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(NASA CR-52634)
CALCULATION OF THE FAR-FIELD ACOUSTIC
EFFECTS OF STATIC TESTING OF LARGE
SPACE VEHICLES

By

Richard N. Tedrick

Feb 14, 1963 32p 11/82

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ABSTRACT

1020³

This report presents methods of calculating the sound pressure levels which may result from static testing of large space vehicles. The effects upon the sound of the directivity of the source and the attenuation of the atmosphere are discussed. Discussion on the effects of the sound energy upon surrounding installations and communities is included. Damage criteria for various types of construction are included along with some preliminary criteria for hearing loss. Predicted acoustic levels for several high-thrust vehicles are presented.

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NTP-TEST-63-3

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TEST DIVISION

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GEORGE C. MARSHALL SPACE FLIGHT CENTER

MSF-TRST-63-3

**CALCULATION OF THE FAR-FIELD ACOUSTIC
EFFECTS OF STATIC TESTING OF LARGE
SPACE VEHICLES**

By

Richard H. Tedrick

SUMMARY

This report presents methods of calculating the sound pressure levels which may result from static testing of large space vehicles. The effects upon the sound of the directivity of the source and the attenuation of the atmosphere are discussed. Discussion on the effects of the sound energy upon surrounding installations and communities is included. Damage criteria for various types of construction are included along with some preliminary criteria for hearing loss. Predicted acoustic levels for several high-thrust vehicles are presented.

SECTION I. INTRODUCTION

One of the by-products of the static testing of rocket-powered space vehicles is the engines' roar. As the size of the vehicle to be tested has risen, so also has the resultant noise level. During the testing of the Saturn vehicle at Marshall Space Flight Center this noise has been propagated across the Redstone Arsenal area and into the surrounding civilian communities. Because of the meteorological factors at the time of firing, part of this acoustical energy has been occasionally focused into the business and residential areas. Such occurrences have heightened the interest in determining what may be the acoustic consequences of static firing larger rocket vehicles, whether they are to be fired at MSFC, or elsewhere.

To judge the effects of such tests, both Saturn static test acoustic data and limited model studies have been utilized. These, it is felt, are useful as bases for extrapolation to full-scale, large-thrust static tests. However these extrapolations only represent the present state of the art in generalized form and should be applied to specific test configurations with extreme caution.

where M is the mass of the exhaust gases in grams and v is the expanded jet velocity in meters per second.

Therefore, for a constant exit velocity

$$\frac{dE}{dt} = \frac{1}{2} v^2 \frac{dM}{dt} \quad (3)$$

However, the time rate of change of the momentum (Mv) of the exhaust gases is by definition the thrust (T), the above equation can be written:

$$\frac{dE}{dt} = \frac{1}{2} vT \quad (4)$$

Now assuming a proportionality (a conversion or efficiency factor) constant (η) equation 4 becomes

$$P_m = \eta \frac{dE}{dt} \quad (5)$$

or in another form

$$P_m = \frac{1}{2} \eta vT \quad (6)$$

For most large rocket firings, the acoustic efficiency factor (η) has been found to equal about 0.0005 (one-half percent). Having no reason to think otherwise, it may be reasonable to assume a similar efficiency for even larger vehicles tested under approximately equal conditions.

It can be shown (Ref. 1) that, ignoring excess attenuation and assuming perfect hemispherical radiation,

$$SPL = P_m - 20 \log r - 18 \quad (7)$$

where r is expressed in meters and the sound pressure level (SPL) is in decibels re: 0.0002 microbars. This can be rewritten as:

$$SPL = 10 \log \eta + 10 \log (1/2) \frac{Tv}{P_0} - 20 \log r - 18 \quad (8)$$

Because: $\text{Area} = \frac{\pi d^2}{4}$

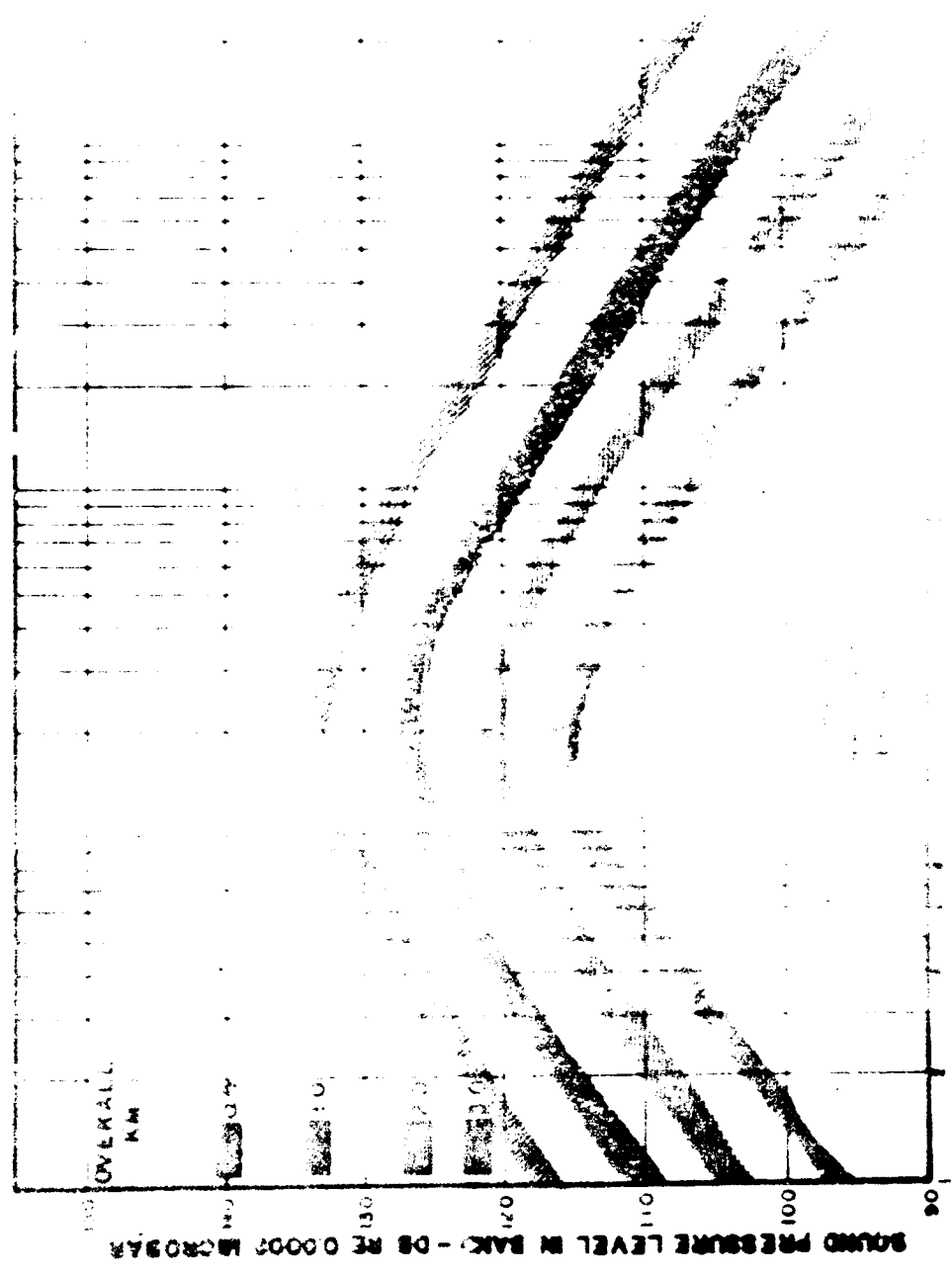
$$d = 2 \sqrt{\frac{\text{HA}}{\pi}}$$

Therefore, d varies as the square root of the thrust and f_{max} is inversely proportional to the square root of the thrust. Actually, the fact that d varies as the square root of the thrust is not only true for clustered engines but is true in general if the expended jet velocity V is held constant. That is approximately the case for all present and presently contemplated liquid fuel engines and many solid fuel engines also.

By utilizing the above relationships to determine the value of the peak frequency and the increase in sound pressure levels over the smoothed Saturn data measured at MSFC, it is possible to calculate the spectra which will result from the testing of vehicles larger than the Saturn. A water-cooled bucket-type deflector similar to the one presently used at the MSFC Saturn test stand must be assumed or else some method devised for correcting the bucket-derived data for the new test stand configuration.

It should be emphasized that the overall levels per se are of only very limited usefulness, since the spectra of the noise must be known so that they may be compared with the various criteria, which are themselves functions of frequency. Accordingly, estimates of the noise spectra to be expected have been prepared from smoothed measured sound pressure spectra for the Saturn, scaled in thrust and frequency as discussed. These estimated spectra for the 7.5-million-pound thrust S-IC vehicle appear in Figure 1, where the sound pressure levels in octave bands and the calculated overall levels are given for various distances from the source. The levels of Figure 1 pertain to the space average; that is, they give the sound pressure levels generated by an equivalent source of the same acoustic power, but one which radiates uniformly in all directions. Directivity corrections must be included, as discussed later, if one wishes to estimate the levels to be obtained from the S-IC at a given location.

Careful examination of Figure 1 will show that the spectra presented fall slightly with increasing distance and frequency. This is due to the atmospheric attenuation discussed later.



FIGURE

SECTION IV. DIRECTIVITY CORRECTION

Figure 2 shows the characteristic directivity pattern for the single bucket deflector configuration.¹ This pattern is based upon recently experimented data obtained at MSFC on scale model experiments with similar deflectors. These data agree in essence with other recent data obtained from full-scale Saturn measurements at ranges of approximately one-half mile range. These data appear to be more meaningful for the acoustic far-field than earlier directivity data obtained at 600-foot range from a full-scale Saturn configuration. The reason that the full-scale Saturn directivity data from one-half mile are not themselves used is that propagation over the distance involved in a 1/20 scale model is less apt to be affected by meteorological conditions.

To find the overall levels in a given direction, one merely adds algebraically the directivity correction shown in Figure 3 to the average levels of Figure 1. This procedure applies approximately to the octave band levels as well, since experimental data indicates that the Saturn noise spectrum does not change drastically with angular orientation. The spectrum changes that do occur would result in levels that would be generally lower than those predicted by the present procedure. So, this method of calculating overall sound pressure levels may be considered to be conservative in the engineering sense. It should be emphasized that these estimates concern mean values only. Large fluctuations are to be expected due to non-homogeneities in the atmosphere itself. (See Ref. 6 for examples and discussion of such fluctuations.)

As an example, consider the following: What is the sound pressure level in the octave band centered around 100 cps in a direction 50 degrees with respect to the exhaust stream, 1.6 kilometers from the S-1C stand? From Figure 1, one finds that the space average sound pressure level in that octave band is approximately 120 db re 0.0002 microbar. From Figure 2, one finds that the directivity correction in the 50-degree direction is +3 db; that is, the actual level is 3 db above the space average, or 123 db re 0.0002 microbar. It is to be noted that the directivity pattern permits one to orient the exhaust stream to achieve some noise reduction at critical points.

1. This directivity characteristic was found experimentally to exist around the Saturn static firings at ranges in excess of 100 nozzle diameters. Below this range the characteristic changes significantly.

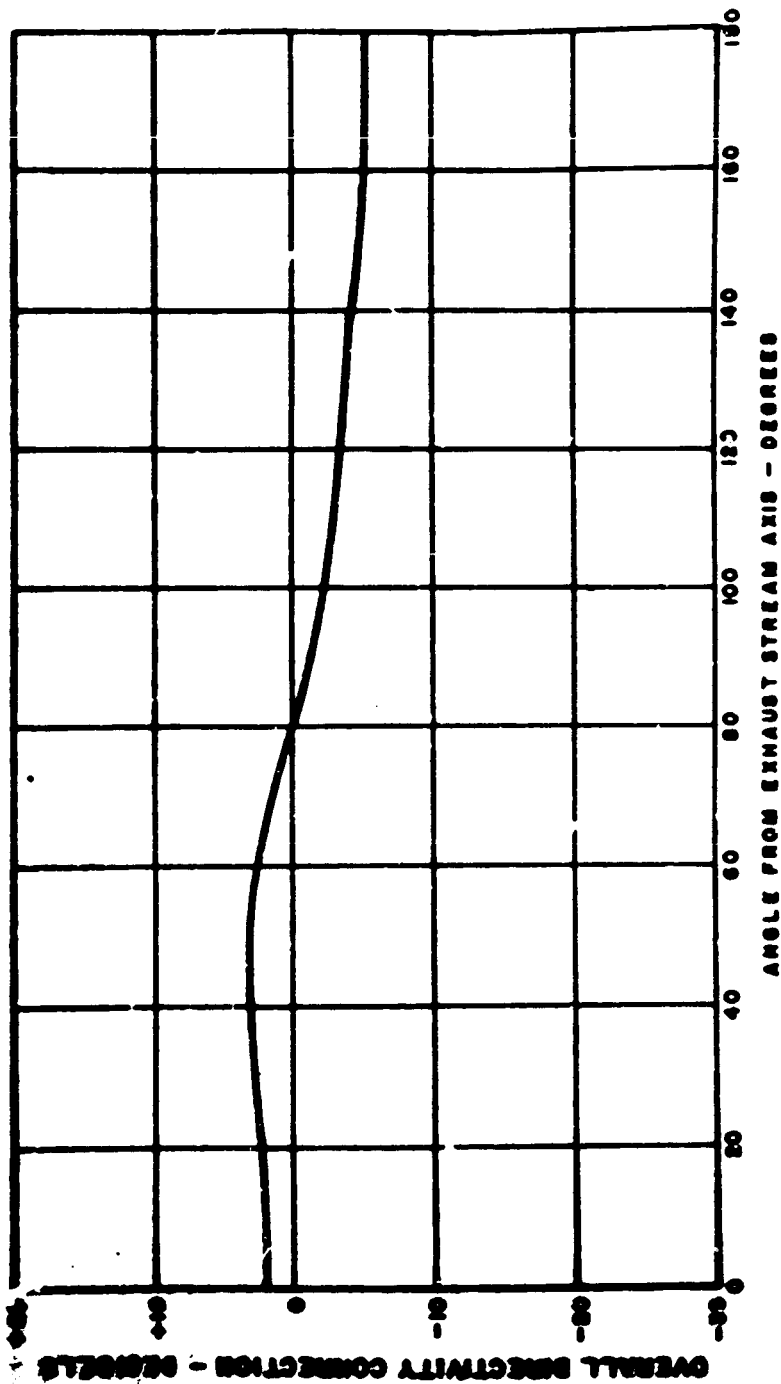


FIGURE 2. MEAN OVERALL DIRECTIVITY PATTERN FOR STATIC TESTING OF LARGE ROCKET MOTORS USING SINGLE BUCKET DEFLECTOR (BASED ON MSFC MODEL TESTS)

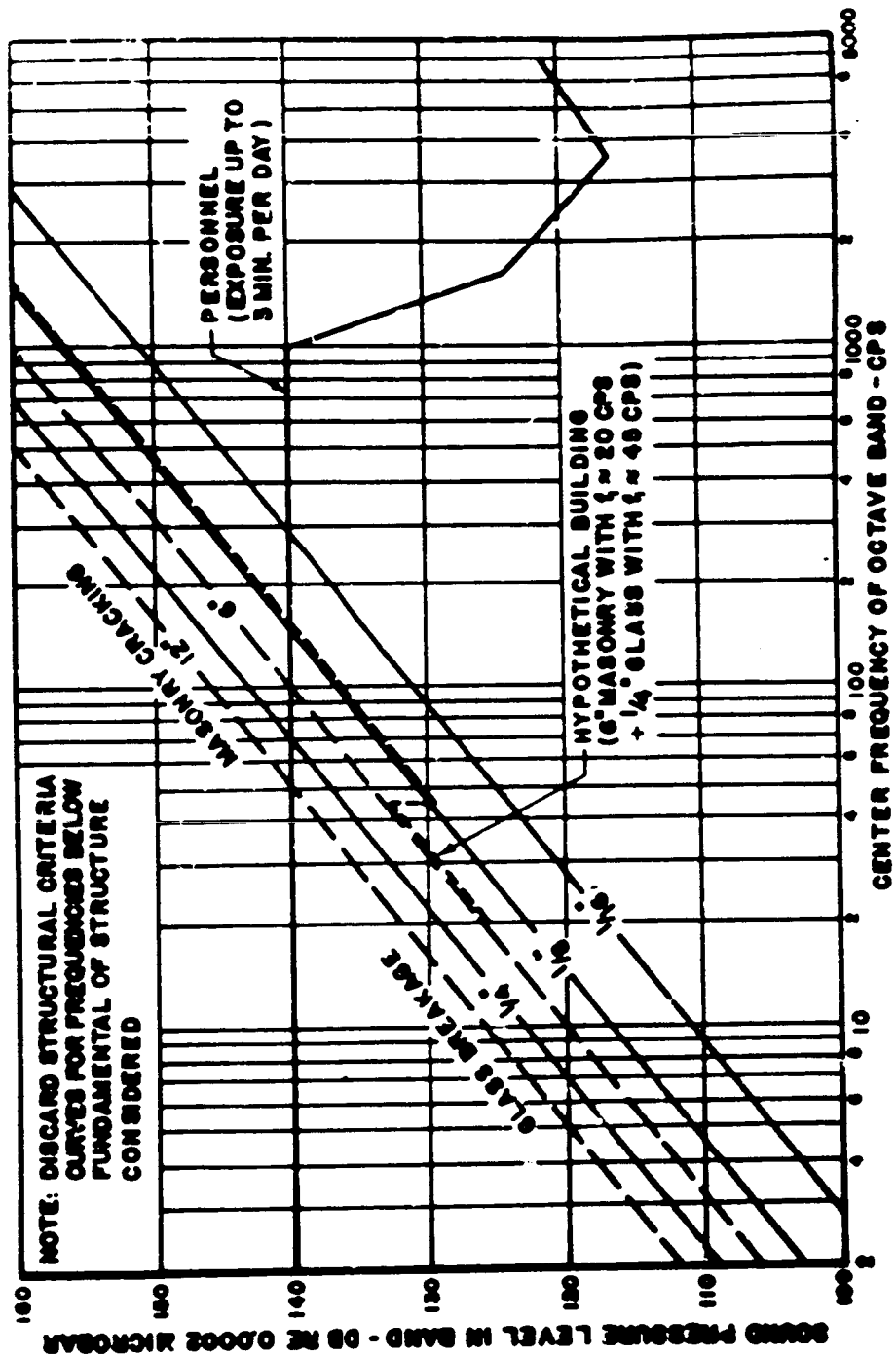


FIGURE 3. NOISE EXPOSURE CRITERIA FOR BUILDING STRUCTURES AND UNPROTECTED PERSONNEL

It is appropriate to stress again that in making use of the data shown in Figure 1 (and similar data for other vehicles) one should use the overall level only in a preliminary way, and then only with caution. All criteria, be they for structural damage, deafness, or annoyance, involve a frequency dependence; therefore, it is essential that the spectral character of the noise be considered in the calculation of relevant hazard contours. It is for this reason that the sound pressure spectra are included in Figure 1.

SECTION V. ATMOSPHERIC EFFECTS

Sound propagation along the ground over distances of several kilometers has been shown to be profoundly affected by the state of the atmosphere between source and receiver. Experimental data on sound transmission of rocket noise over long distances, that are well-documented by simultaneously obtained meteorological measurements are only recently becoming available, largely through the measurement program in progress at Test Division at MSFC. Moreover, a comprehensive theory is still lacking. Despite this lack of understanding of the physics of sound transmission through the atmosphere, quantitative engineering estimates must still be made. In arriving at these estimates the following procedure has been followed with some success. It is assumed that the total excess attenuation (the difference in decibels between the actual attenuation measured and the level reduction based on inverse-square law alone) measured at a given distance in a given frequency band can be separated into two parts: First, the sum total of dissipative effects in the atmosphere, primarily molecular absorption. Second, the loss (or gain) due to atmospheric refraction, including scattering losses by turbulence and impurities.

Assuming that the excess attenuation effects are separable, it should be observed that the excess attenuation of the first type can be approximated by an attenuation coefficient which is dependent upon distance. This attenuation coefficient also depends not only on the signal frequency but also on bandwidth and spectrum shape. (Estimates of the effective attenuation coefficient are given in Table I below). These estimates are based on air-to-ground propagation data¹ obtained from Figure 9-10 in Reference 3 and have been adjusted to take account of the spectrum shape of rocket noise. The attenuation data

1. In air-to-ground propagation over relatively short distances ground sound refraction effects are likely to be small. However their direct application to the ground-level static testing situation has yet to be proved.

presented in Reference 5 is based mainly upon an Air Force-Armour Research Foundation study which showed similar values for low frequency atmospheric attenuation. No allowance was made in these studies for attenuation by ground cover. Although no specific data are available, it is believed that the absorption over open level country with grass and sparse shrubs may be considered to be small at the low frequencies which are important in rocket noise.

Table I

Estimated Dissipative Excess Attenuation in the Atmosphere

Freq. Band, 8-16	16-35	35-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800
(cps)								
Atten. Coef.	1/3	1/3	5/6	1 1/2	2	2 2/3	4	5 1/3
($\frac{db}{km}$)								8 1/3

Note: Attenuation Coefficient at very low frequencies (≈ 1 cps) = 0

The estimates of the overall sound pressure levels, the octave band spectra given in the preceding section, were arrived at by using the above figures as "average atmospheric attenuation." Unfortunately, there are few experimental data available against which these estimates can be checked at this time because sound transmission data from static testing of large boosters involve sound refraction as well (see below). However, there are some data which are applicable because the slope of the effective sound velocity profile is small (of the order of 1 meters/second per kilometer.)

(a) Sound pressure spectra from SA-1 Saturn launch. (Ref. 6)
The data are applicable because the average gradient of the sound velocity profile at the approximate height was not appreciable.

(The velocity of sound, c , varied less than plus or minus three meters per second per one kilometer altitude.)

(b) Sound pressure spectra during static testing of Saturn at NRC. There are as yet few spectral analyses of the far-field sound pressures available. However, the spectra measured during test SA-06 ($\alpha = 3$ meters/sec./km) compare generally with the spectra predicted on the basis of the method outlined in this report.

There is experimental evidence that good correlation exists between the effective attenuation (positive or negative) due to sound refraction and the mean slope (negative or positive) of the effective sound velocity profile with height. (Ref. 7)

The velocity of propagation of sound c , at a given height, and in a given direction, may be defined as equal to the speed of sound at the temperature at the point in question in still air, and added to it the vector component of the mean wind at that height in the direction considered. As a consequence, the effective velocity of propagation of sound c varies not only with height but also with azimuth because of the influence of the wind.

The variations of c with height tend to refract the sound "rays." If the slope of the velocity profile in the atmosphere near the ground between source and receiver is positive, that is if the effective speed of propagation of sound increases with height, the sound "rays" are bent toward the ground. This may result in the formation of a sound "focus," or large negative values of excess attenuation. If the slope of the velocity profile is negative, the sound "rays" are bent upward, away from the ground. This may result in the formation of a sound "shadow," or large positive values of excess attenuation. (Ref. 7 & 8)

To assess the likelihood of occurrence of these effects and their magnitude, it is necessary to construct the probability distributions of the sound velocity profiles and their seasonal variations using weather data from nearby meteorological stations. Because this report is not intended to be restricted to any specific area or areas, no such probability distributions are included herein.

SECTION VI. CRITERIA FOR EVALUATING ANTICIPATED SOUND PRESSURE LEVELS

There are several possible approaches to evaluating the anticipated sound pressure levels. Some previously suggested criteria (Ref. 5) are given in terms of maximum permissible overall sound pressure level without regard to the spectral composition of the generated noise. However, it is felt best to use building and personnel damage criteria expressed in terms of sound pressure level given in band sound pressure levels not to be exceeded.

The above-mentioned criterion based on overall sound pressure level indicated that residential building structures may suffer damage when they are exposed to noise with an overall sound pressure level exceeding 120 db re 0.0002 microbar. This criterion was established essentially for one specific purpose: to estimate what damage might occur in the residential areas surrounding the Cape Canaveral Missile Test Annex area during launches of Nova vehicles in support of the Apollo program. Thus, the overall SPL criterion was intended to apply primarily to existing residential buildings located outside the controlled area, and was designed to aid in balancing the costs of damages against the cost of land acquisition.

For the purposes of this report, however, the authors are interested not only in the residential areas outside the controlled zone, but also in the effects of static tests upon structures and personnel in the controlled zone, itself. Moreover, the range of thrusts of vehicles to be tested encompasses one order of magnitude, with corresponding changes in the frequency spectrum of the noise. Hence it is more appropriate to use damage criteria in which frequency information is retained.

It is well known that structures are most likely to be damaged by noise when they are excited at a resonance, and that the lowest resonance is usually associated with the greatest damage causing potential. For example, a wall or a window which may be damaged by noise with a 120 db octave band sound pressure level in a band encompassing its fundamental frequency may be able to withstand levels up to 126 db in the next higher octave band. This assumes that the higher octave band encompasses higher resonance frequencies of the structures considered; if not, then this band only excites modes off resonance and its damage-causing potential is much reduced.

Residential structures outside controlled areas may have components (walls, windows, roof panels) with all sorts of values of fundamental resonant frequencies. Thus, communities of reasonable size may be expected to harbor some structures with fundamental frequencies that will fall within the octave band corresponding to the peak of the noise spectrum generated by any given large booster. The overall levels associated with rocket noise depend, for all practical purposes, only on the three or four octave bands nearest the spectral peak (the spectrum shapes near the peaks do not vary very much). Therefore, establishment of an overall level criterion is essentially establishing an octave band criterion for structures (with some assumed average thickness and strength characteristics) with resonances that fall near the spectral peak.

The heavy solid curve of Figure 2 represents the maximum sound pressure levels to which personnel without ear protection may be exposed for up to three minutes per day, suffering appreciable hearing loss. This proposed design concerns only the effect of the noise on the threshold of hearing of the subjects during the recent laboratory tests from which the criteria were derived (see below). The sound was a direct effect on the ears of the subjects (by means of earphones) without exposure to the body. This, of course, is not the case when a person is exposed to rocket noise outdoors. Neither does this criterion take into account such effects as surprise, attitude, response, or impairment of a person's ability to perform mental or physical tasks (such as driving a vehicle).

The maximum sound pressure level to which personnel may be exposed for up to three minutes per day, suffering appreciable hearing loss, is shown in Figure 2 by the heavy solid curve. The maximum sound pressure level to which personnel may be exposed for up to three minutes per day, suffering appreciable hearing loss, is shown in Figure 2 by the heavy solid curve. The maximum sound pressure level to which personnel may be exposed for up to three minutes per day, suffering appreciable hearing loss, is shown in Figure 2 by the heavy solid curve.

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We should note that the criteria pertain to conventional or "average" structures and that non-conventional design (such as the use of laminated glass, sand-filled binder blocks) may result in configurations able to withstand much higher sound pressure levels than those shown in Figure 2.

Consider, for example, a building with 6-inch thick cinder block walls and double strength (1/8 in. thick) windows, where the largest window is 2 ft x 2 ft (f_1 45 cps), and the largest wall is 10 ft x 20 ft (f_1 20 cps). By choosing the lowest of the applicable criterion curves, recalling that each is to be used only above the corresponding fundamental frequency, one obtains the composite criterion labeled "hypothetical building" in Figure 2. Note that here the masonry criterion controls below 45 cps, since the window criterion applies only above 45 cps.

Figure 4 shows hazard contours applicable to the static firing of 7.5-million-pound thrust S-IC boosters into a water-cooled single bucket deflector. These contours were obtained by comparing the spectra given in Section II with the criteria of Figure 2 and provide an idea how far structures or personnel should be kept from the S-IC test stand. Because of their symmetry about the exhaust direction, only one half of each contour is shown.

Also shown in Figure 4 is the estimated contour corresponding to a 125 db overall sound pressure level, as obtained from Figure 1. It is evident that use of a 125 overall db sound pressure level criterion in the present case would be over-conservative for nearly all types of structures one would reasonably consider for a test site.

In view of the frequency dependence of the damage criteria, it is clear that an overall sound pressure level criterion cannot be very useful by itself, since it discards all spectrum information. Thus, for example, an overall sound pressure level of 125 db obtained from Saturn contains considerably more high frequency energy than the same level from Nova. Consequently, although both spectra would be represented by the same overall level, Nova's spectrum would result in a greater hazard to structures with low resonances, whereas Saturn's would be a greater hazard to personnel (since hearing is more likely to be impaired by higher frequencies).

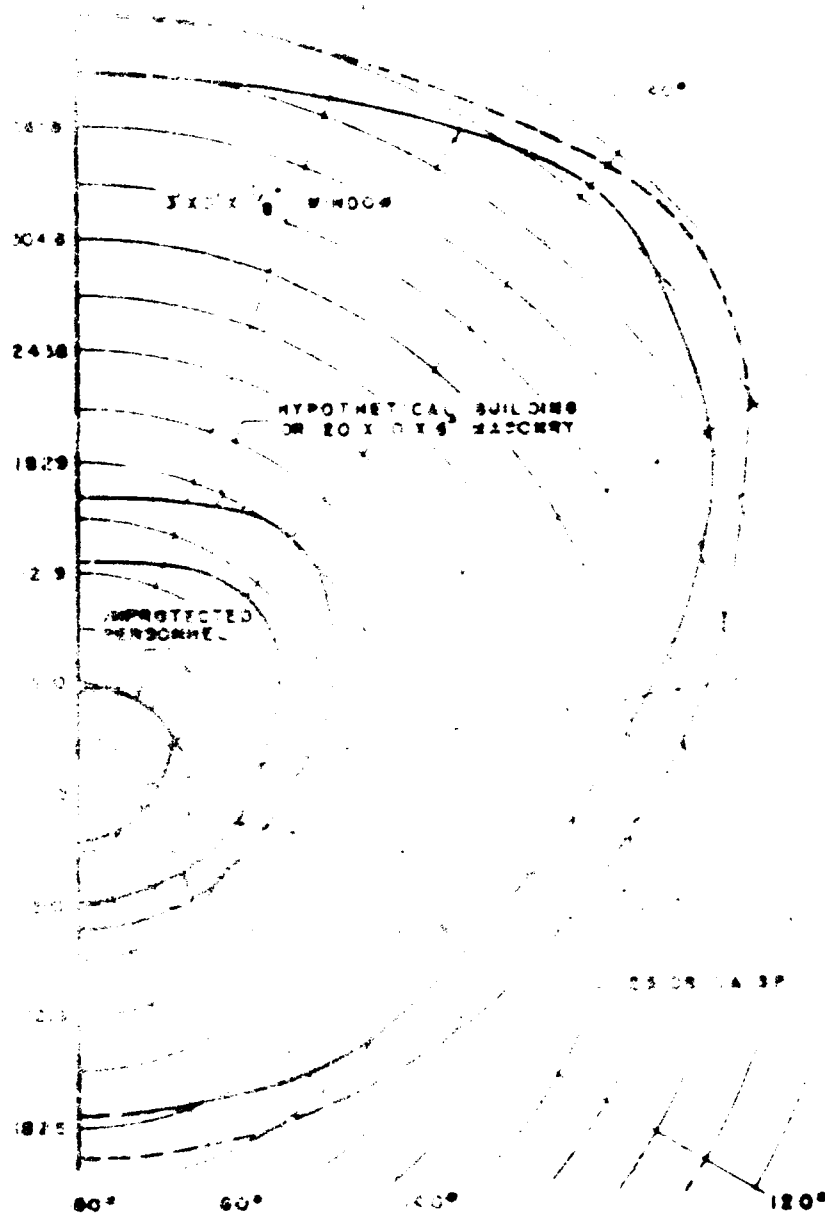


FIGURE 4. ACOUSTICAL HAZARD CONTOURS: S-1C (7.5×10^6 LB THRUST) FIRING INTO SINGLE BUCKET DEFLECTOR

APPENDIX

CALCULATED ACOUSTIC LEVELS FOR SEVERAL HIGH THRUST-LEVEL VEHICLES

The methods outlined in the main body of this report have been applied to the calculation of the sound pressure levels which may be expected from static tests of several high thrust vehicles. These levels, plus the contours (isopleths) around the static test stands at given discrete values, are given in this Appendix for arbitrarily chosen thrust values. Vehicles of these specific thrusts may or may not ever be tested. However the charts and tables in this Appendix sound pressure levels from a wide range of thrusts.

Certain assumptions were made in the calculation of the levels presented herein. The applicability of these assumptions to any specific test need to be considered before the figures listed in this Appendix are used for that test.

The primary assumption made was that the larger thrust boosters would be static tested under conditions identical to those under which the Saturn S-IC was tested at MSFC. This then included firing on a single water-cooled bucket-type deflector whose water-mass to propellant-mass ratio is one-to-one. Under these conditions the acoustic efficiency is about one half of one per cent and the directivity is that shown in Figure 3 of the main body of this report.

The other assumption basic to these calculation is that the vehicles are either liquid-fueled or of an engine type which has the same acoustic efficiency as the liquid-fueled Saturn S-IC.

The effects of changing any of the above parameters are not yet completely understood and therefore the acoustic results of the testing under other conditions may vary significantly from the predictions listed in this Appendix.

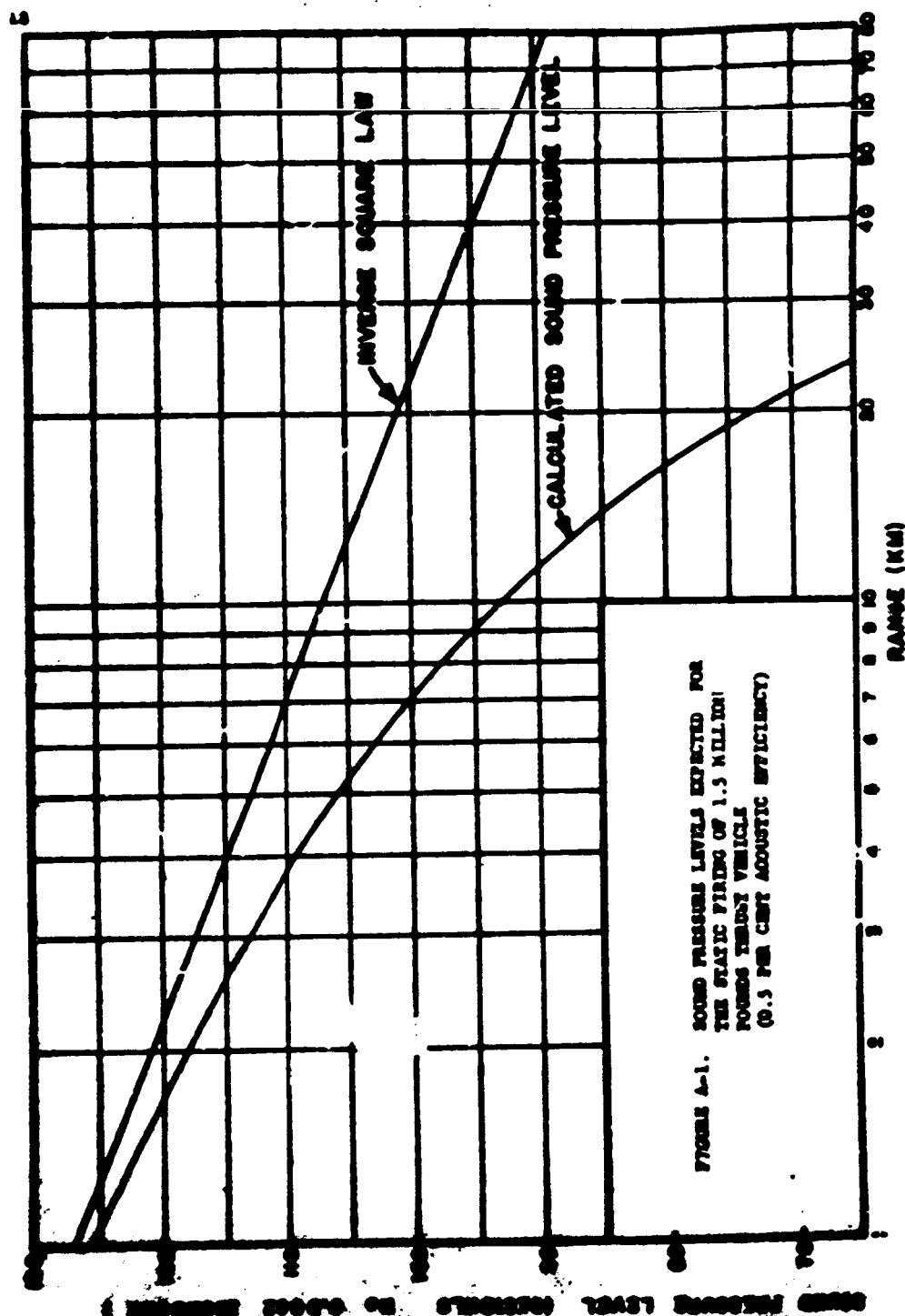
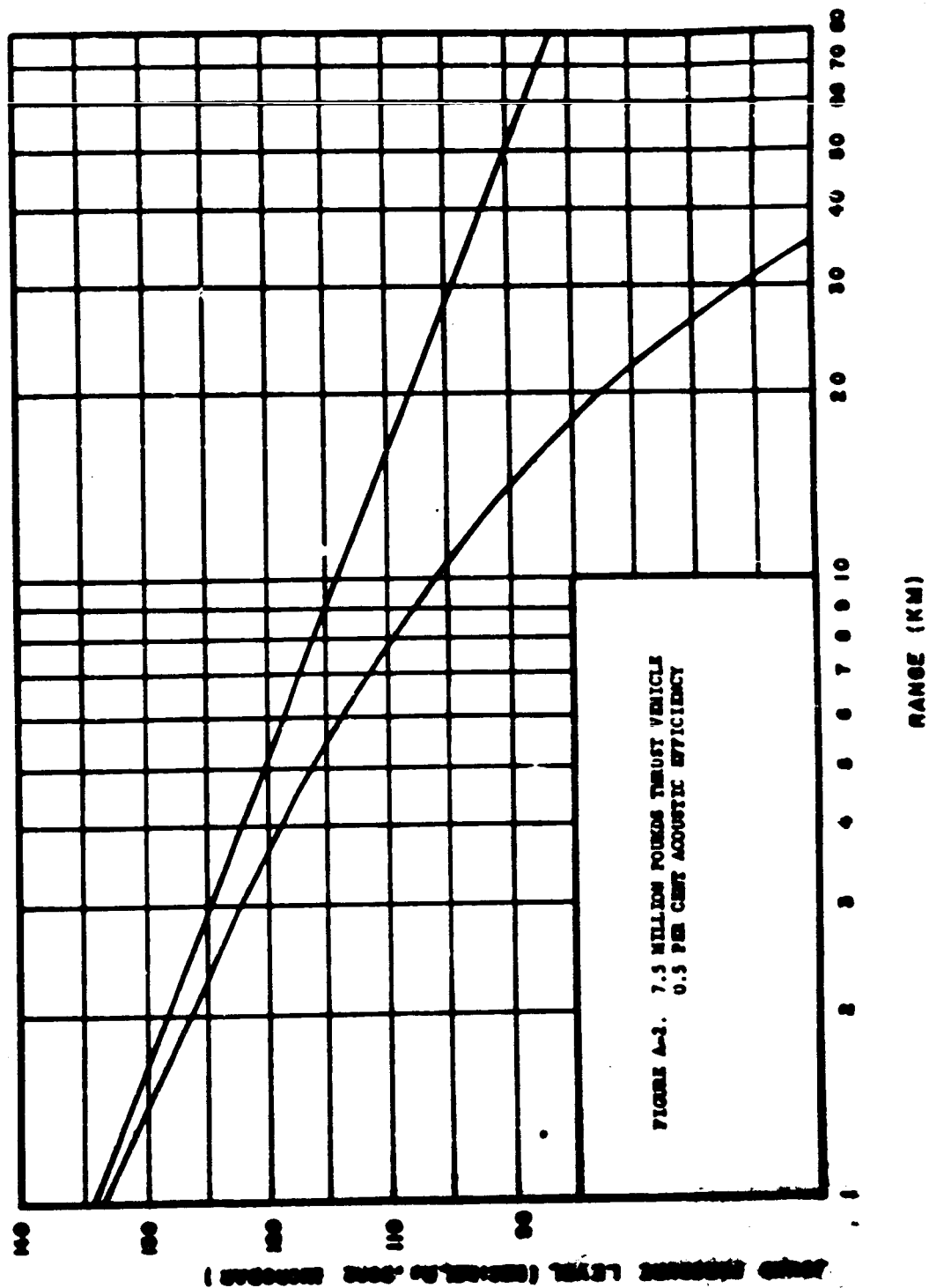


FIGURE A-1. SOUND PRESSURE LEVELS EXPECTED FOR THE STATIC FIRING OF 1.5 MILLION POUND THRUST VEHICLE (0.5 PER CENT ACOUSTIC EFFICIENCY)



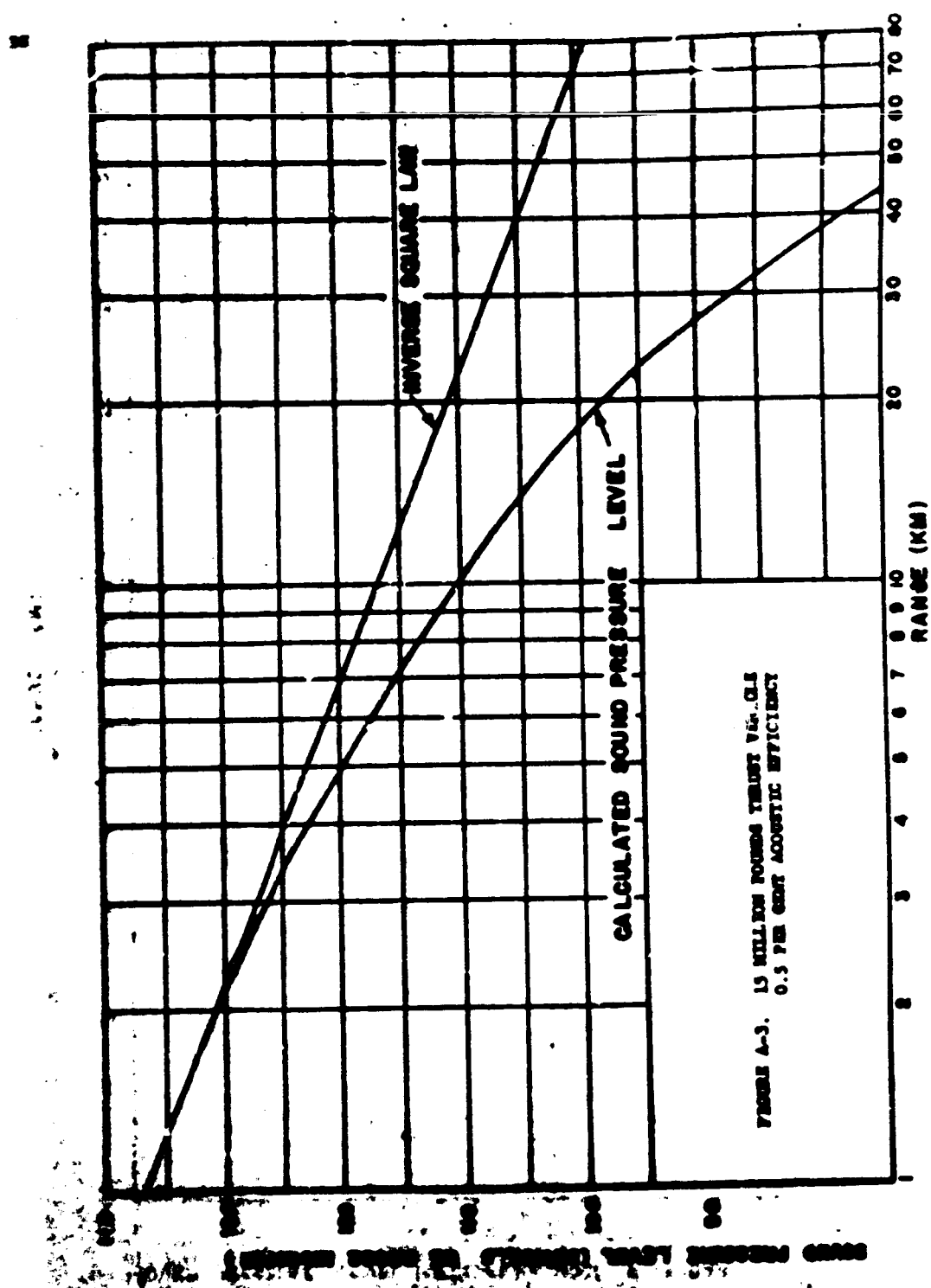
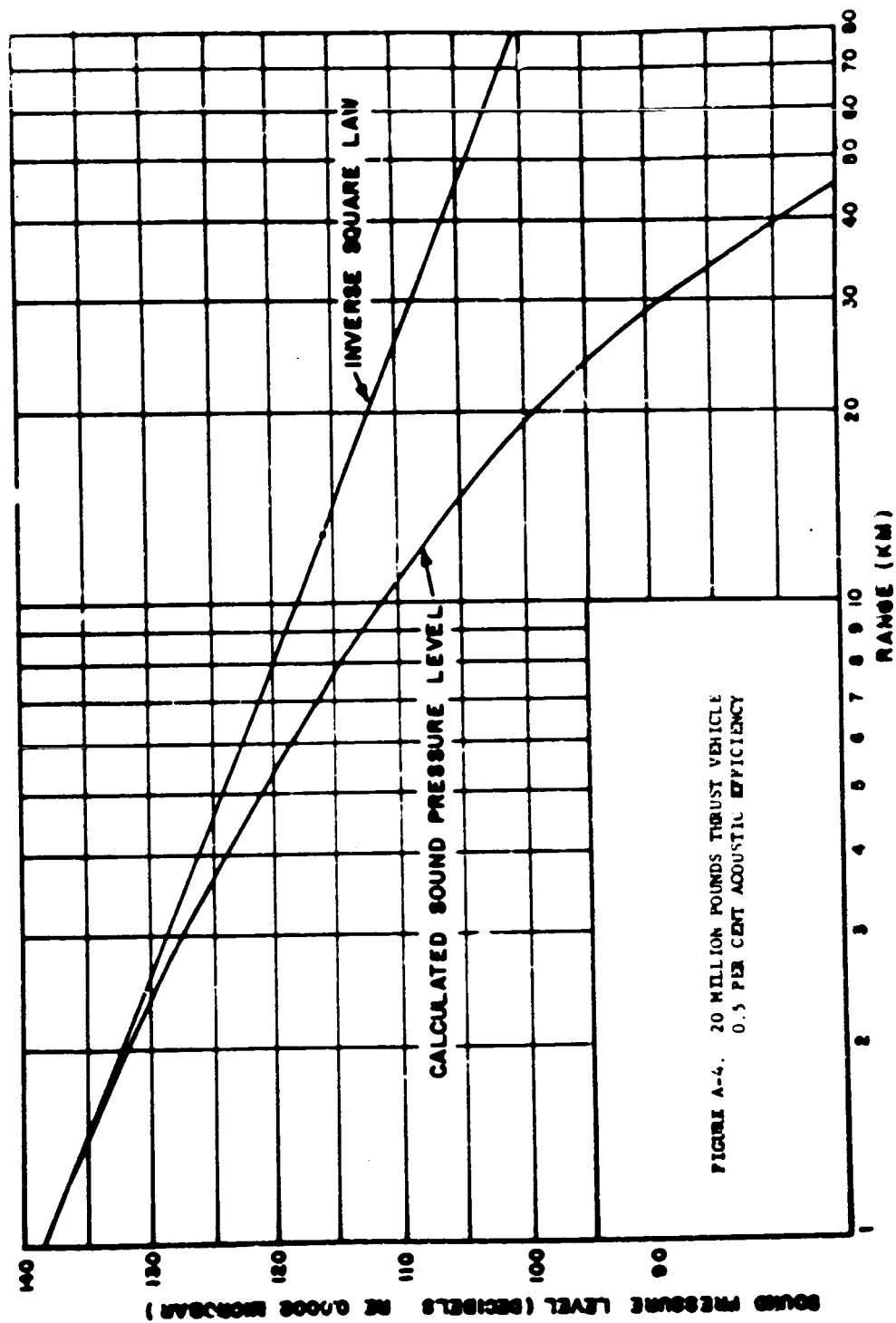


FIGURE A-3. 15 MILLION POUNDS THRUST V4-GLS
0.5 PER CENT ACOUSTIC EFFICIENCY



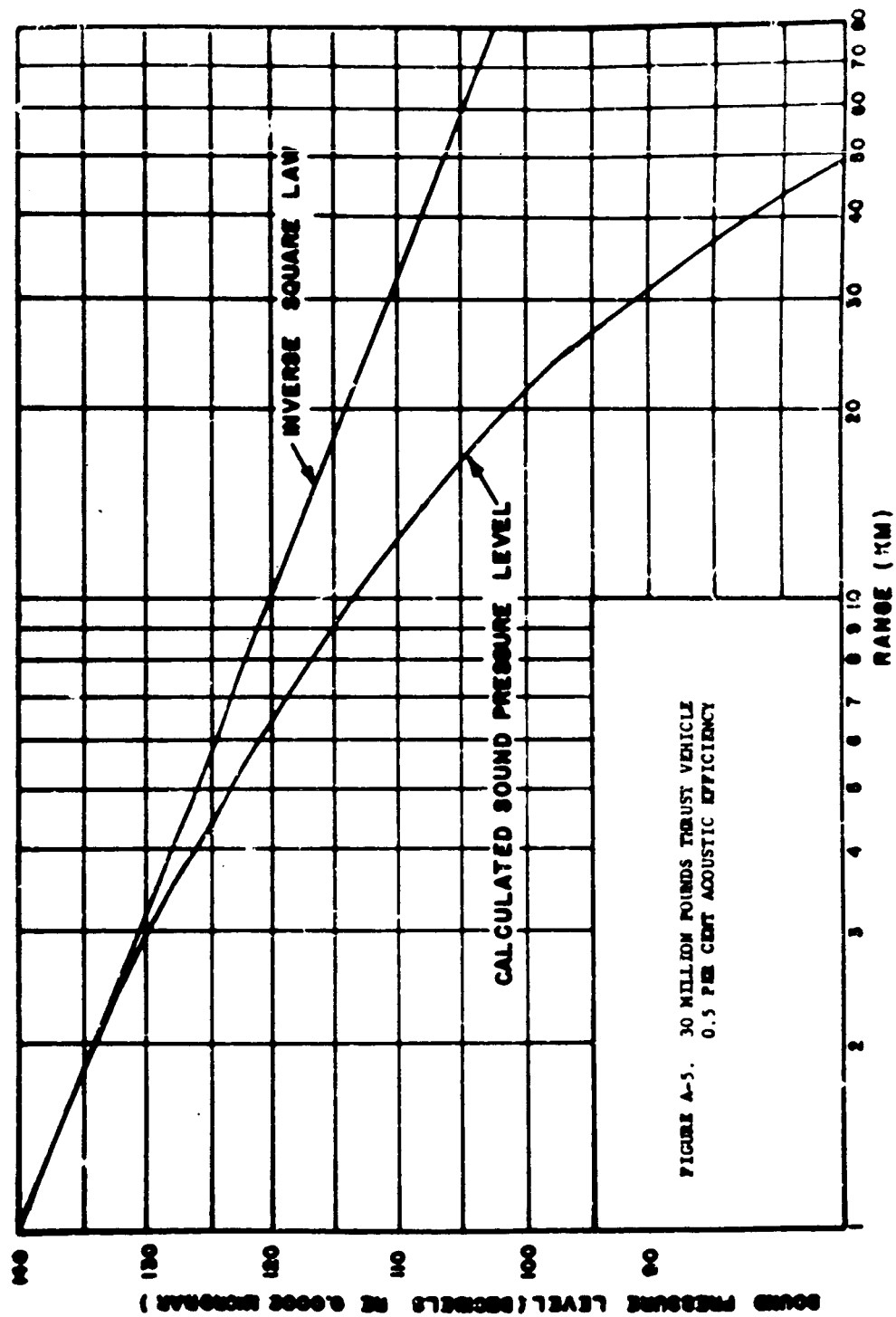


FIGURE A-5. 30 MILLION POUNDS THRUST VEHICLE
0.5 PER CENT ACOUSTIC EFFICIENCY

TABLE A-1
Anticipated Sound Pressure Level Contours
1.5 Million Pounds Thrust

<u>Azimuth*</u>	<u>120 db (meters)</u>	<u>110 db (meters)</u>	<u>105 db (meters)</u>	<u>100 db (meters)</u>
0°	2,063	4,612	6,445	8,641
15°	2,063	4,612	6,445	8,641
30°	2,165	4,839	6,862	9,067
45°	2,194	4,904	6,853	9,189
60°	2,034	4,547	6,354	8,520
75°	1,773	3,962	5,446	7,424
80°	1,700	3,800	5,310	7,120
90°	1,555	3,475	4,856	6,511
105°	1,337	2,998	4,175	5,599
120°	1,206	2,696	3,767	5,051
135°	1,104	2,468	3,449	4,625
150°	1,032	2,306	3,222	4,321
165°	988	2,209	3,086	4,138
180°	959	2,144	2,144	4,016

*Azimuth is measured from the centerline of the single bucket-type deflector.

TABLE A-2
Anticipated Sound Pressure Level Contours
7.5 Million Pounds Thrust

<u>Azimuth*</u>	<u>120 db</u> <u>(meters)</u>	<u>110 db</u> <u>(meters)</u>	<u>105 db</u> <u>(meters)</u>	<u>100 db</u> <u>(meters)</u>
0°	4,328	9,266	12,649	16,917
15°	4,328	9,266	12,649	16,917
30°	4,342	9,662	13,198	17,648
45°	4,603	9,815	13,381	17,892
60°	4,267	9,144	12,466	16,673
75°	3,658	7,955	10,851	14,507
80°	3,566	7,620	10,394	13,899
90°	3,261	6,828	9,297	12,436
105°	2,804	5,974	8,138	10,881
120°	2,530	5,426	7,407	9,906
135°	2,317	4,968	6,767	9,053
150°	2,164	4,633	6,340	8,474
165°	2,073	4,450	6,066	8,108
180°	2,012	4,298	5,883	7,864

*Azimuth is measured from the centerline of the single bucket-type deflector.

18

25

TABLE A-3
Anticipated Sound Pressure Level Contours
15 Million Pounds Thrust

<u>Azimuth*</u>	<u>120 db</u> <u>(meters)</u>	<u>110 db</u> <u>(meters)</u>	<u>105 db</u> <u>(meters)</u>	<u>100 db</u> <u>(meters)</u>
0°	6,129	12,137	16,628	21,846
15°	6,129	12,137	16,628	21,846
30°	6,431	12,735	17,447	22,923
45°	6,518	12,906	17,681	23,231
60°	6,042	11,966	16,393	21,539
75°	5,266	10,427	14,051	18,461
80°	5,050	10,000	13,700	18,000
90°	4,619	9,145	12,529	16,462
105°	3,971	7,863	10,772	14,154
120°	3,582	7,094	9,719	12,769
135°	3,280	6,495	8,899	11,692
150°	3,064	6,068	8,312	10,923
165°	2,935	5,812	7,962	10,461
180°	2,849	5,641	7,728	10,154

*Azimuth is measured from the centerline of the single bucket-type deflector.

TABLE A-4

Anticipated Sound Pressure Level Contours
20 Million Pounds Thrust

<u>Azimuth*</u>	<u>120 db</u> <u>(meters)</u>	<u>110 db</u> <u>(meters)</u>	<u>105 db</u> <u>(meters)</u>	<u>100 db</u> <u>(meters)</u>
0°	6,676	13,108	17,720	23,242
15°	6,676	13,108	17,720	23,242
30°	7,004	13,754	18,593	24,387
45°	7,399	14,938	18,801	24,715
60°	6,581	12,923	17,470	22,914
75°	5,735	11,262	15,224	19,968
80°	5,500	10,890	14,600	19,150
90°	5,030	9,877	13,352	17,513
105°	4,324	8,492	11,480	15,058
120°	3,901	7,662	10,357	13,585
135°	3,573	7,016	9,484	12,439
150°	3,338	6,554	8,860	12,124
165°	3,196	6,277	8,486	11,130
180°	3,103	6,092	8,236	10,802

*Azimuth is measured from the centerline of the single bucket-type deflector.

TABLE A-5

Anticipated Sound Pressure Level Contours
30 Million Pounds Thrust

<u>Azimuth*</u>	<u>120 db</u> <u>(meters)</u>	<u>110 db</u> <u>(meters)</u>	<u>105 db</u> <u>(meters)</u>	<u>100 db</u> <u>(meters)</u>
0°	7,767	14,807	19,662	25,245
15°	7,767	14,807	19,662	25,245
30°	8,151	15,537	20,631	26,489
45°	8,260	15,745	20,906	26,844
60°	7,658	14,598	19,385	24,889
75°	6,673	12,721	16,892	21,689
80°	6,400	12,200	16,200	20,800
90°	5,853	11,157	14,815	19,022
105°	5,033	9,593	12,738	16,355
120°	4,540	8,655	11,492	14,756
135°	4,165	7,925	10,523	13,511
150°	3,884	7,403	9,831	12,622
165°	3,720	7,091	9,415	12,089
180°	3,610	6,882	9,138	11,734

*Azimuth is measured from the centerline of the single bucket-type deflector

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APPROVAL

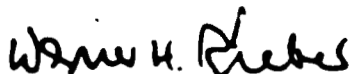
MTP-TEST-63-3

CALCULATION OF THE FAR-FIELD ACOUSTIC EFFECTS OF STATIC
TESTING OF LARGE SPACE VEHICLES

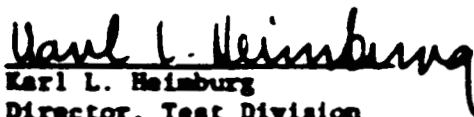
By

Richard W. Tedrick

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